

A photograph of an astronaut working on the Hubble Space Telescope in space. The astronaut is visible in the center, working on the telescope's structure. The telescope's large solar panels are visible at the top, and a large white boom with the word "Canada" is on the right. The Earth's horizon is visible in the background, with a bright light source creating a lens flare effect.

Science and Satellite Servicing

24 March 2010

Matt Mountain

Space Telescope Science Institute



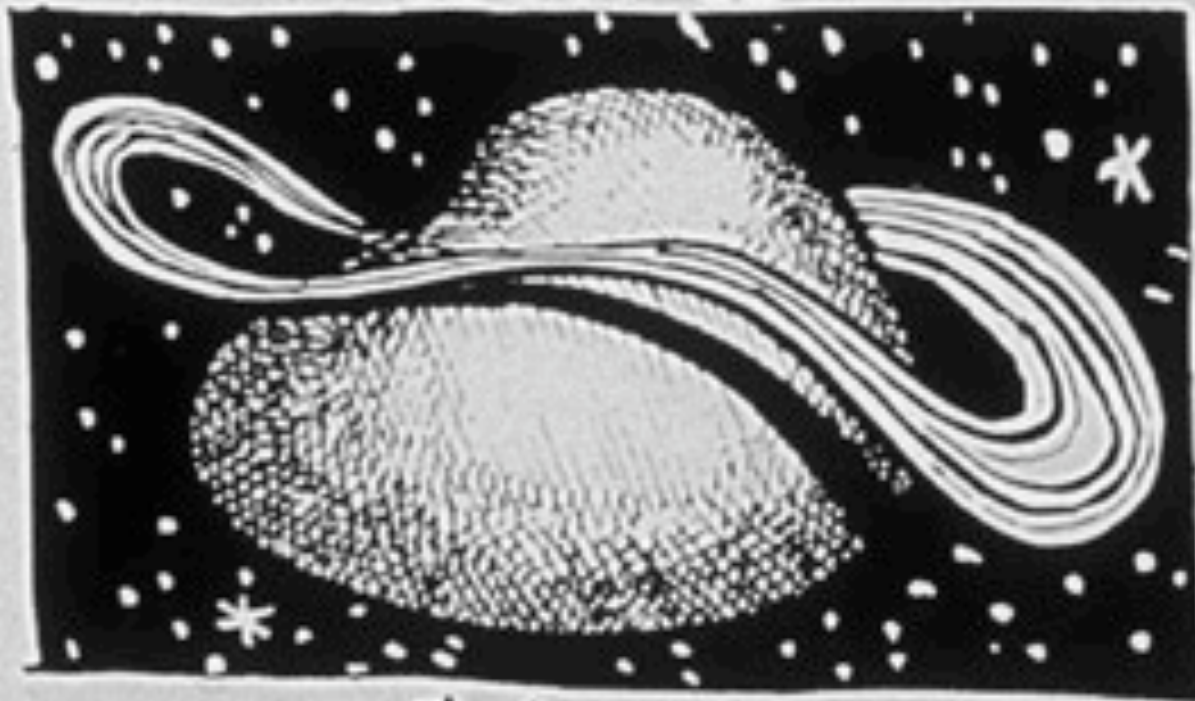
First photos from the Hubble



The moon



Jupiter



Saturn

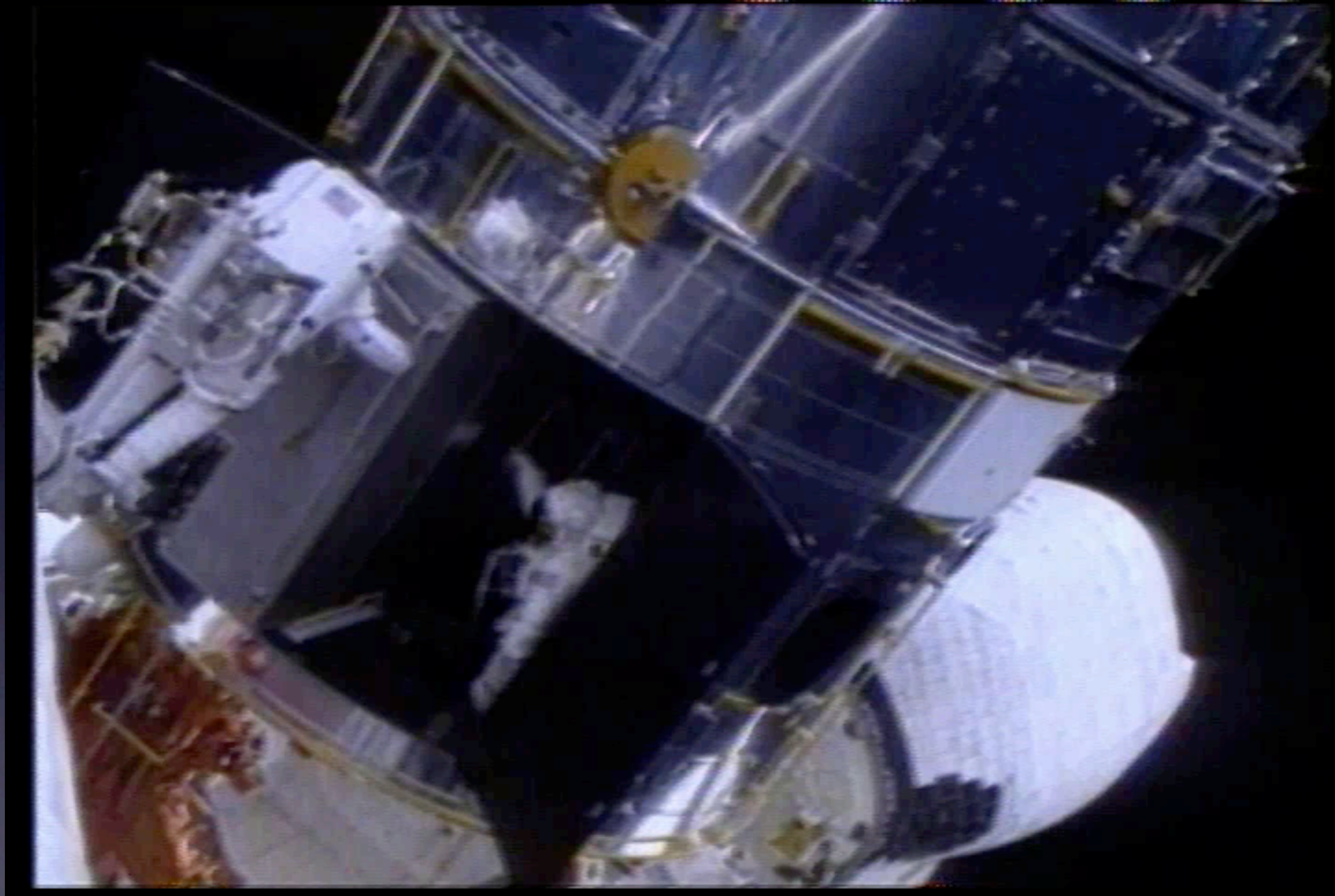


Taxpayers

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The Hubble Space Telescope - launched 1990



servicing makes Hubble unique

“The Trouble with Hubble is Over!” - Senator Barbara Mikulski



A new camera WFPC-2, and corrective optics (COSTAR) made the telescope even better than the original specifications

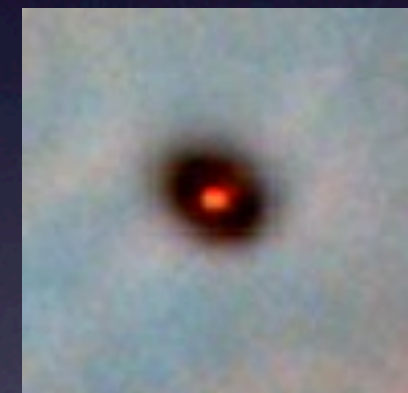
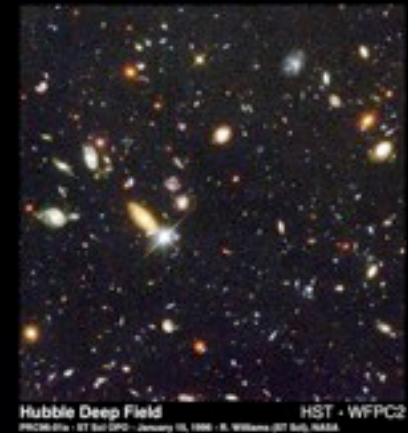
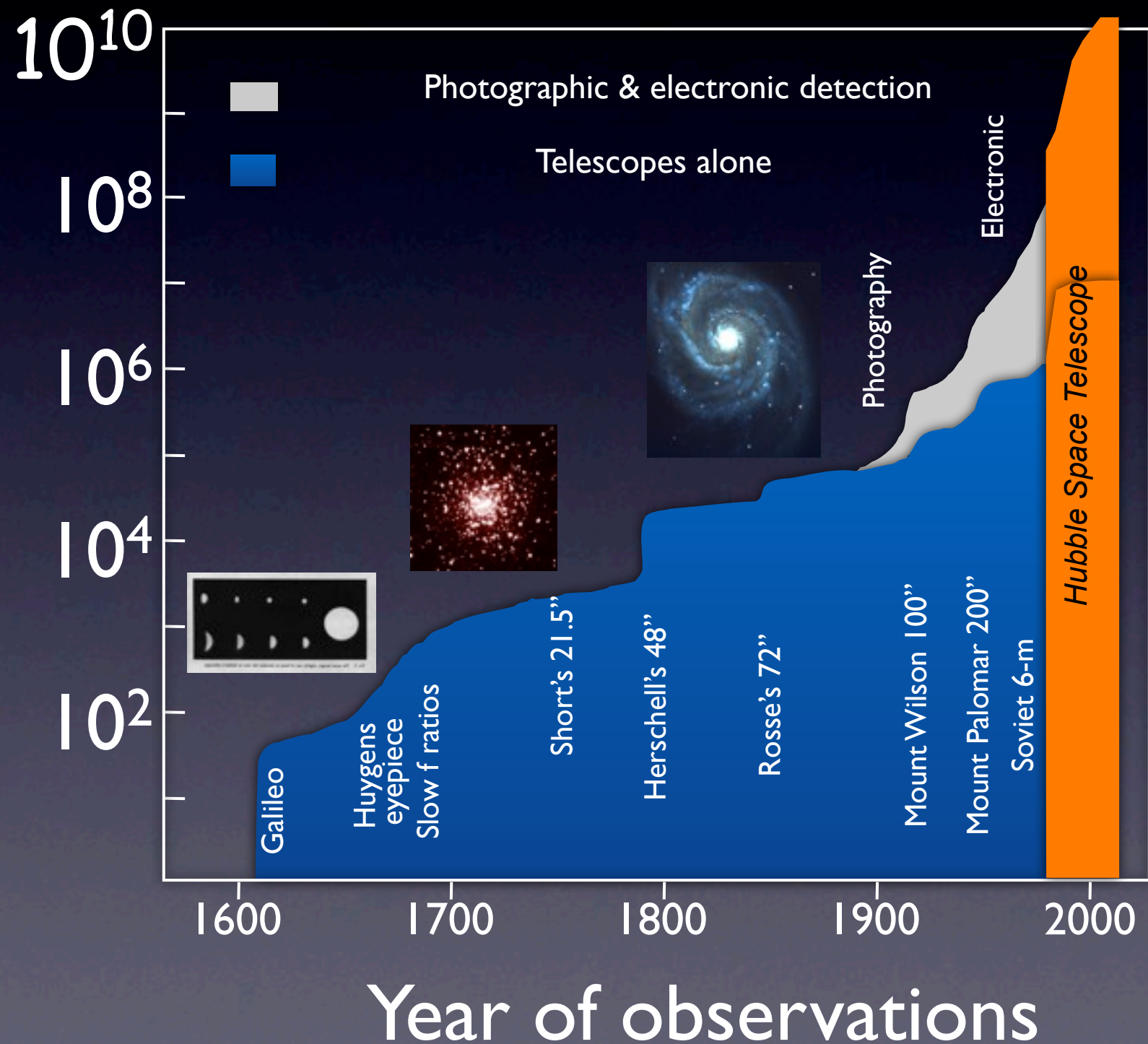
Science and Satellite Servicing

Lesson I

If you screw up, you can fix things

Sensitivity Improvement over the Eye

After Fig. 3.10 in *Cosmic Discovery*, M. Harwit



Hubble Missions

SM4



Gyros
Wide Field Camera 3
Cosmic Origins Spectrograph
Batteries
Fine Guidance Sensor
STIS Repair
ACS Repair
New Outer Blanket Layer
Soft Capture Mechanism

SM3B



Advanced Camera
Solar Arrays
Power Control Unit
NICMOS Cooling
System

SM3A



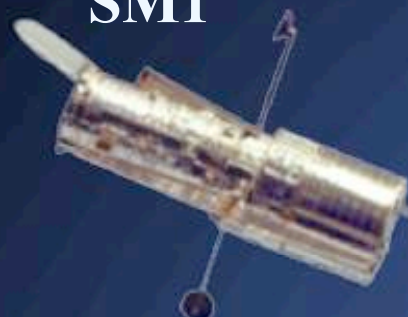
Gyros
Advanced Computer
Fine Guidance Sensor

SM2



Imaging Spectrograph
Near Infrared Camera
Fine Guidance Sensor

SM1



Wide Field Planetary Camera 2
COSTAR
Gyros
Solar Arrays

Launch!



1990

1993

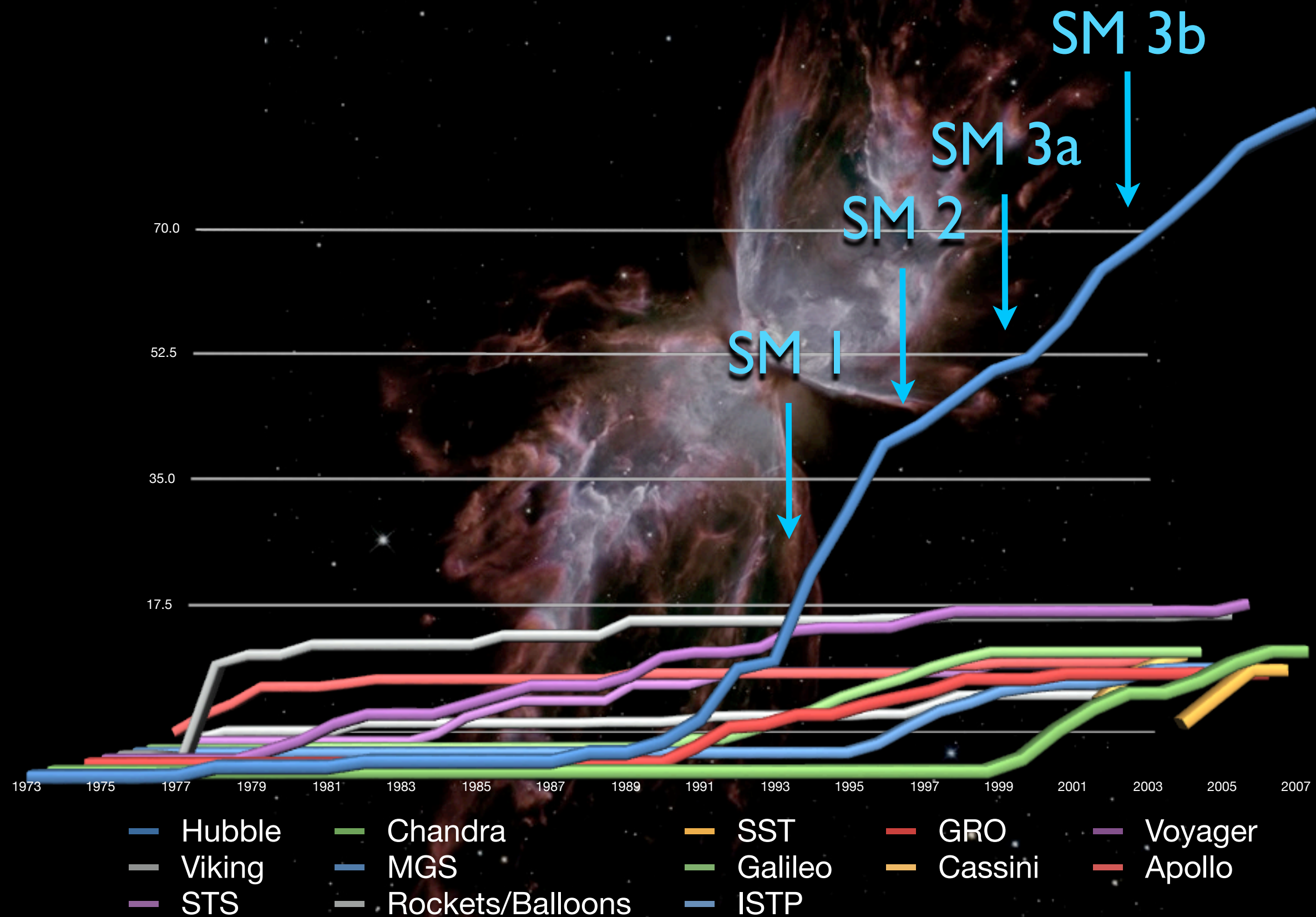
1997

1999

2002

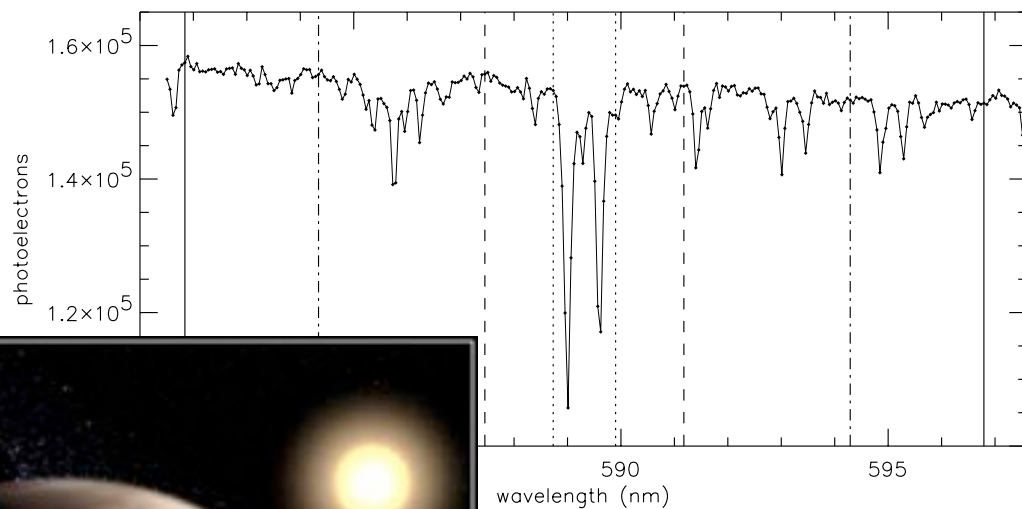
2009

“Davidson” metric, NASA contributions to worldwide scientific discovery and technological achievement

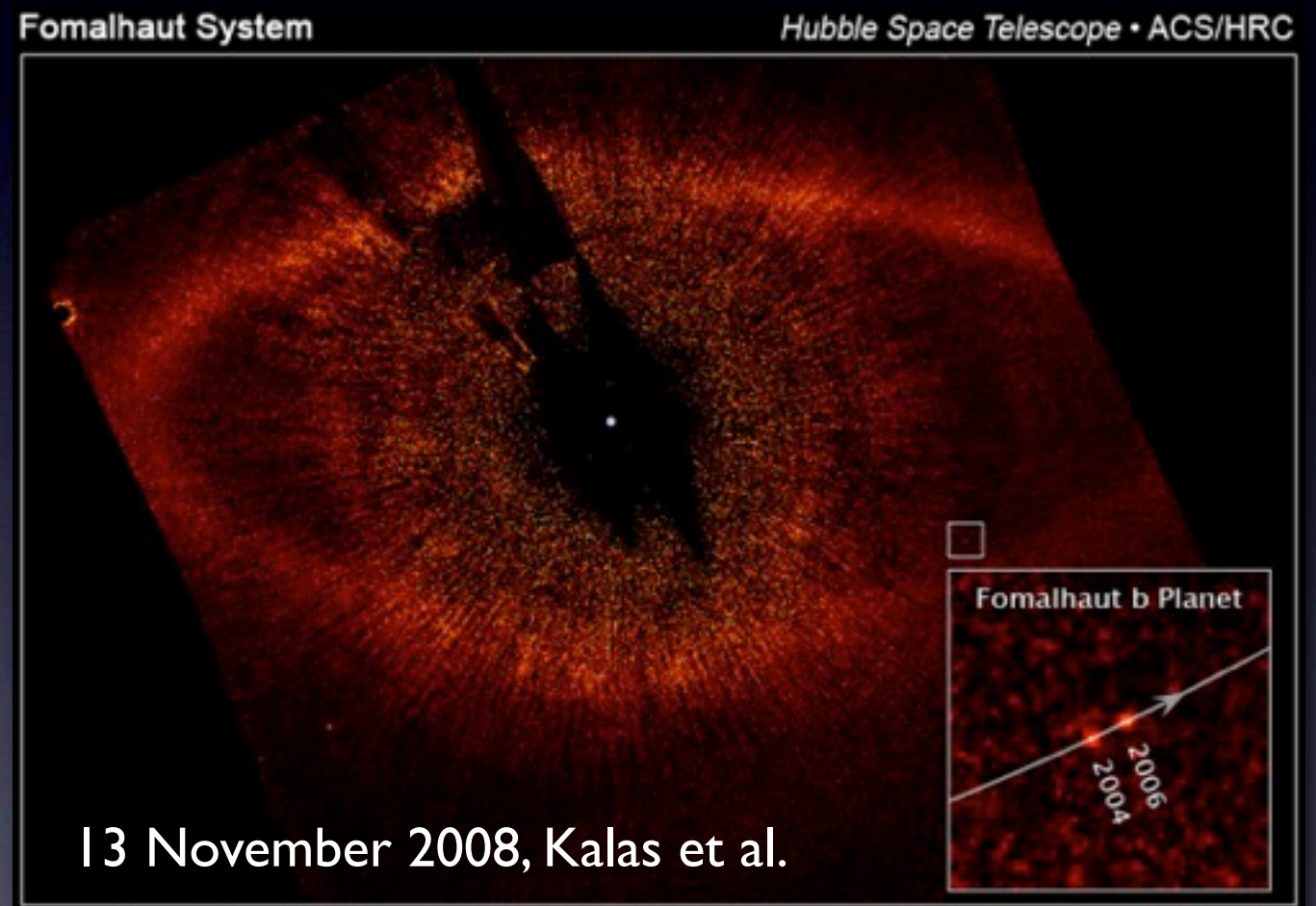


The first extra-solar planet was discovered 6 years after Hubble's launch, and new instruments were required to make these observations

HD 209458b Charbonneau et al, 2002



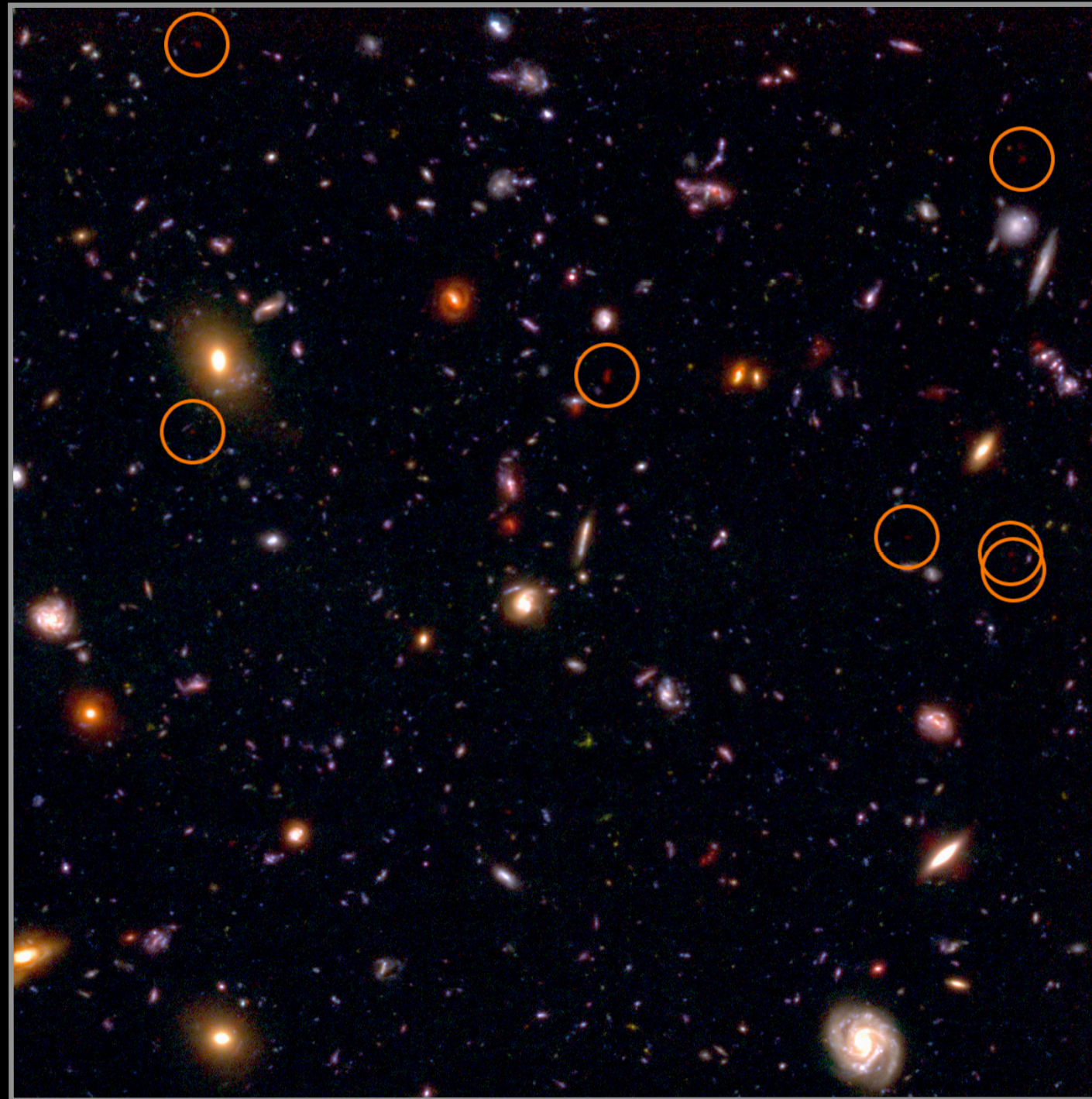
2001 - first spectra
with STIS installed 1997



13 November 2008, Kalas et al.

2008 - first image
with ACS installed 2002

2010 Hubble images **early galaxies** with WFC-3 installed 2009



Hubble Ultra Deep Field

○ galaxies from when the Universe was less than 600 Myr old

This is only possible with new camera technologies

the highest redshift $z \sim 8$ galaxies

(Bouwens et al and
Oesch et al papers)

ACS

filters

WFC3/IR

V

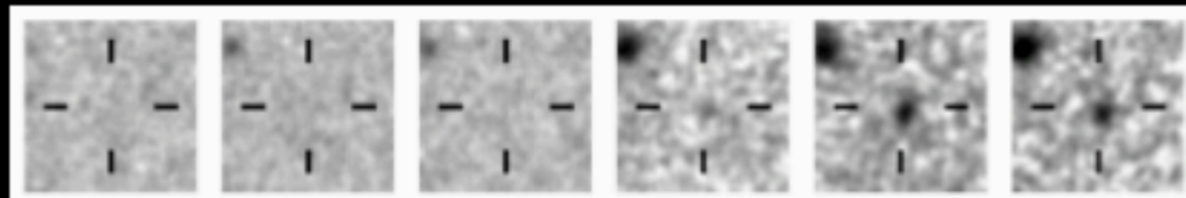
i

z

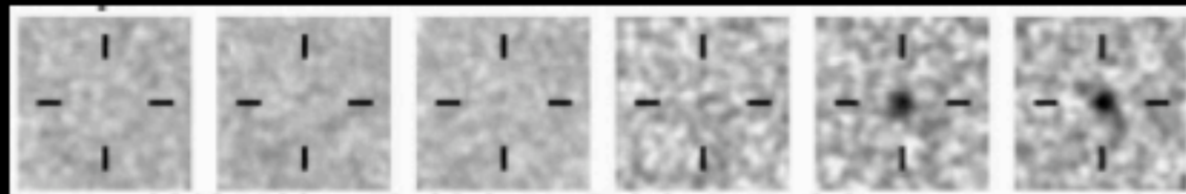
Y

J

H



redshift
 $z \sim 8.4$

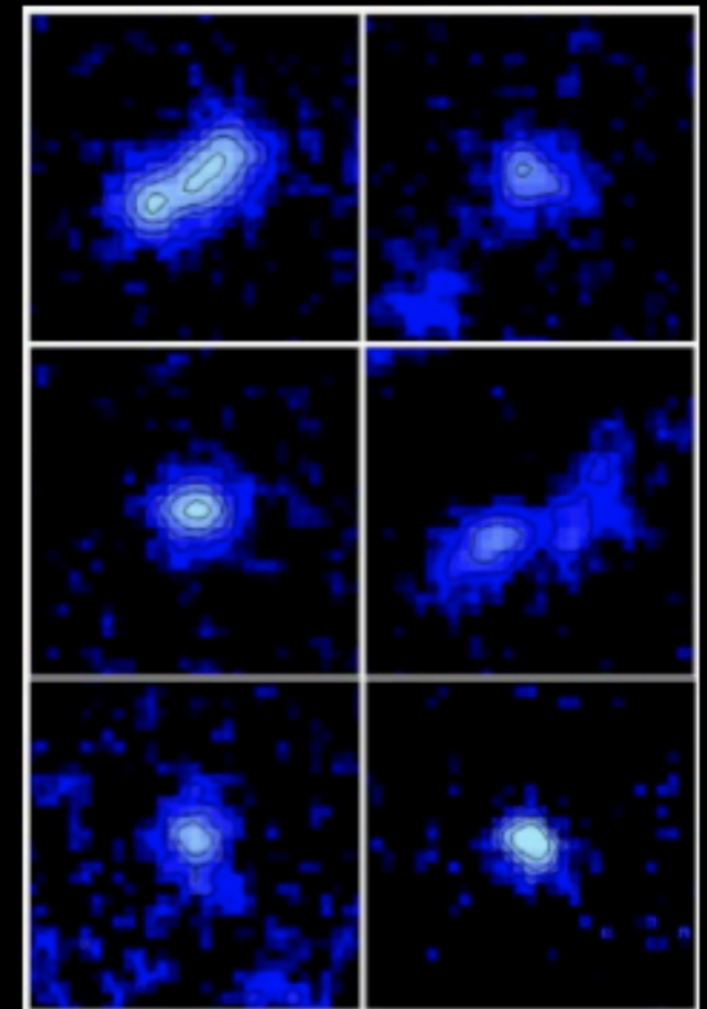


$z \sim 8.7$

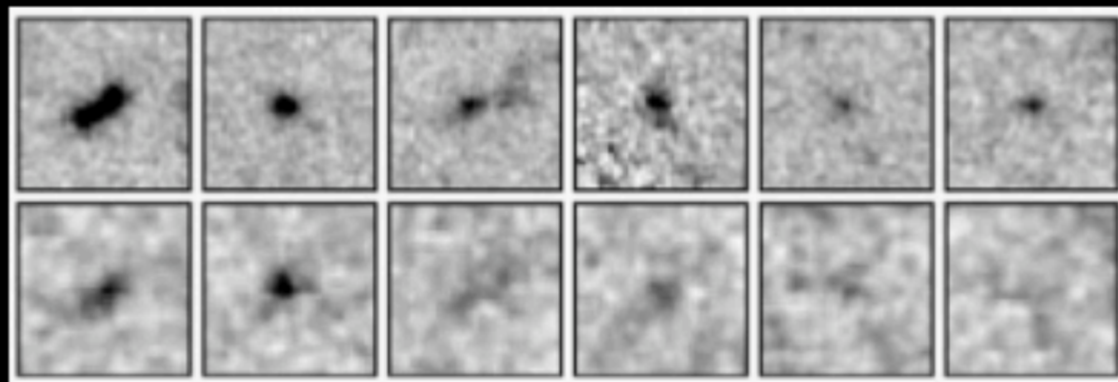
not detected

detected

redshift $z \sim 7$ galaxy images



comparing the old and new Hubble infrared cameras



WFC3/IR

NICMOS

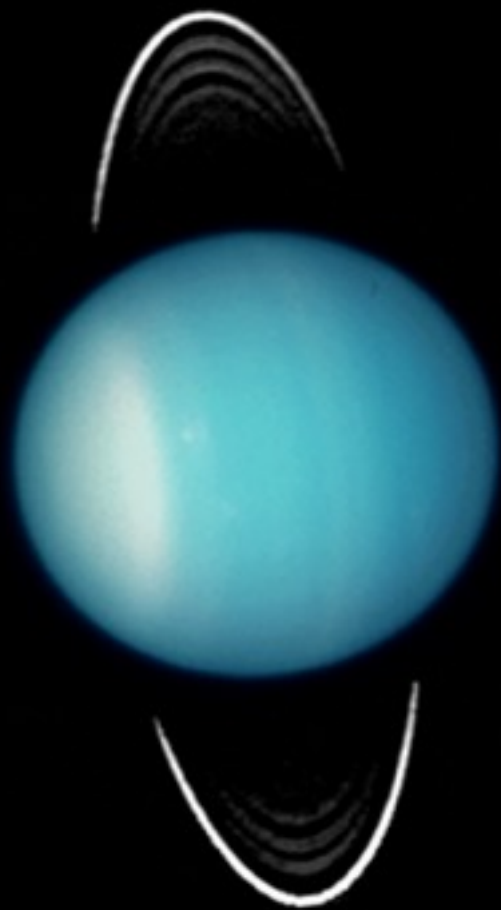
galaxies in the first 700 million years Garth Illingworth www.firstgalaxies.org gdi@ucolick.org

Science and Satellite Servicing

Lesson 2

New technologies enable new science
and science can change faster than mission life cycles

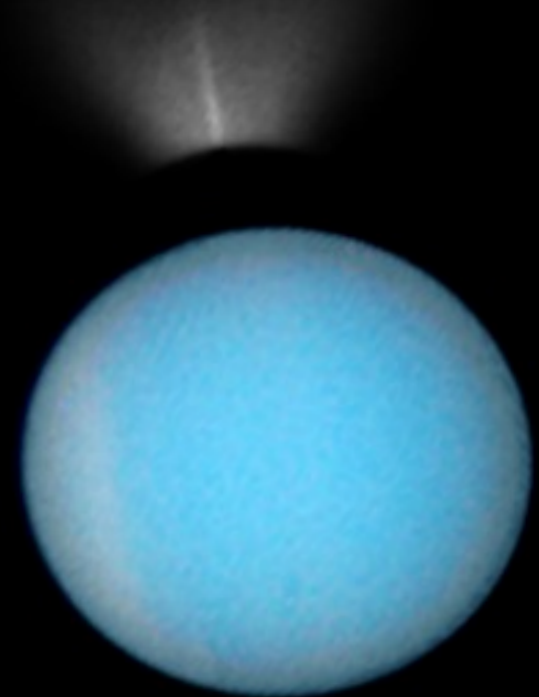
HST can observe changing phenomena



2003



2005



2007

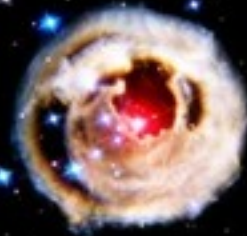
V838 Mon Light Echo
HST ACS/WFC
Hubble Heritage



May 20, 2002



September 2, 2002



October 28, 2002



December 17, 2002



February 8, 2004

V838 Mon, ACS
2002-2004

HST can observe
changing
phenomena



Sep. 24, 1994

WFPC2



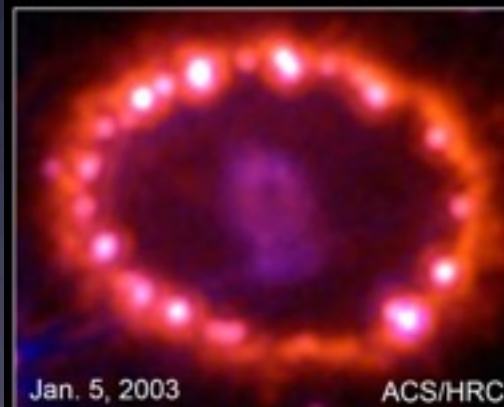
Feb. 6, 1998

WFPC2



Mar. 23, 2001

WFPC2



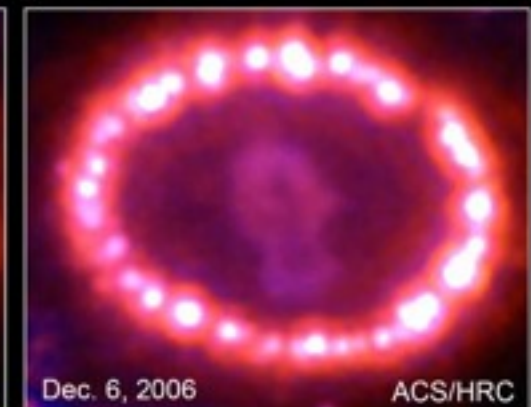
Jan. 5, 2003

ACS/HRC



Dec. 12, 2004

ACS/HRC



Dec. 6, 2006

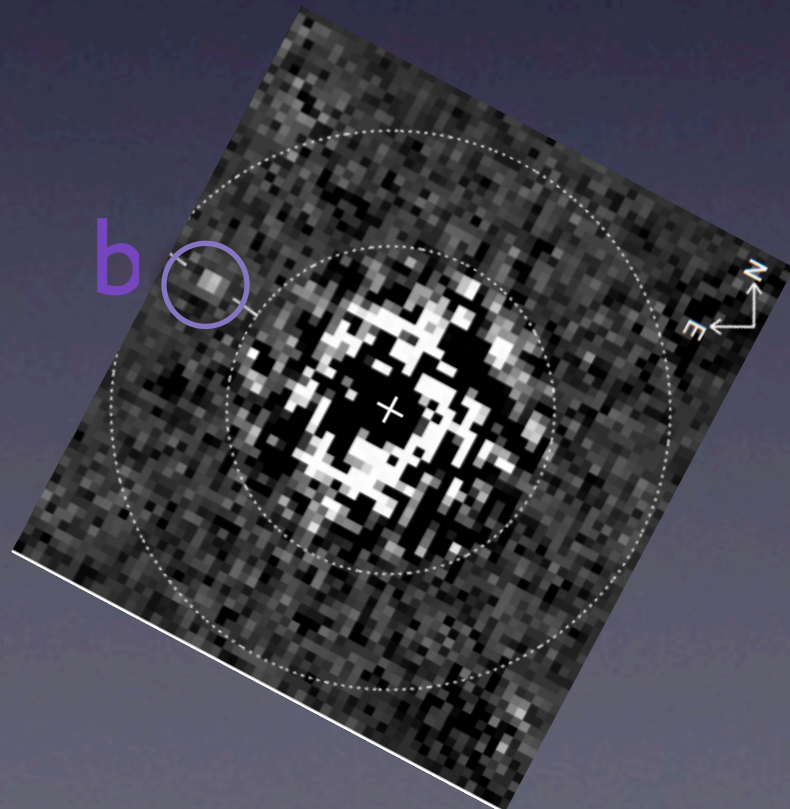
ACS/HRC

SN 1987a, ACS 1994-2006

Science and Satellite Servicing

Lesson 3

Longevity can enable new science



Planet HR 8799 b hidden in
Hubble's data archive since 1998
extracted by Lafreniere et al. 2009

Longevity → Influence

THE NEW YORK TIMES **EDITORIALS/LETTERS** FRIDAY, MAY 3, 2002

The Hubble Achievement

It seems hard to believe that we have already grown used to seeing images from the Hubble Space Telescope in the dozen years since it was first launched. But the startling pictures released this week from a newly restored Hubble are a reminder that we had, in fact, begun to take for granted our ability to peer into deep space, an ability no generation of humans has ever possessed before. In a sense, these new images, produced with cameras and power sources that were added or rejuvenated during a space shuttle flight in March, feel something like learning to see all over again. They remind us what an astonishing chapter of astronomical understanding, for scientists and laymen alike, the Hubble Space Telescope has opened.

the real wonder appears. Beyond the uniformity of the naked-eye universe, there is this other universe, the one Hubble discovers with astonishing clarity. This is a place full of discordant objects, of cataclysmic disturbances. Galaxies devour each other. Stars form in infernos of gas and dust and light. And they do so against the backdrop of a sky that is almost unimaginably deep.

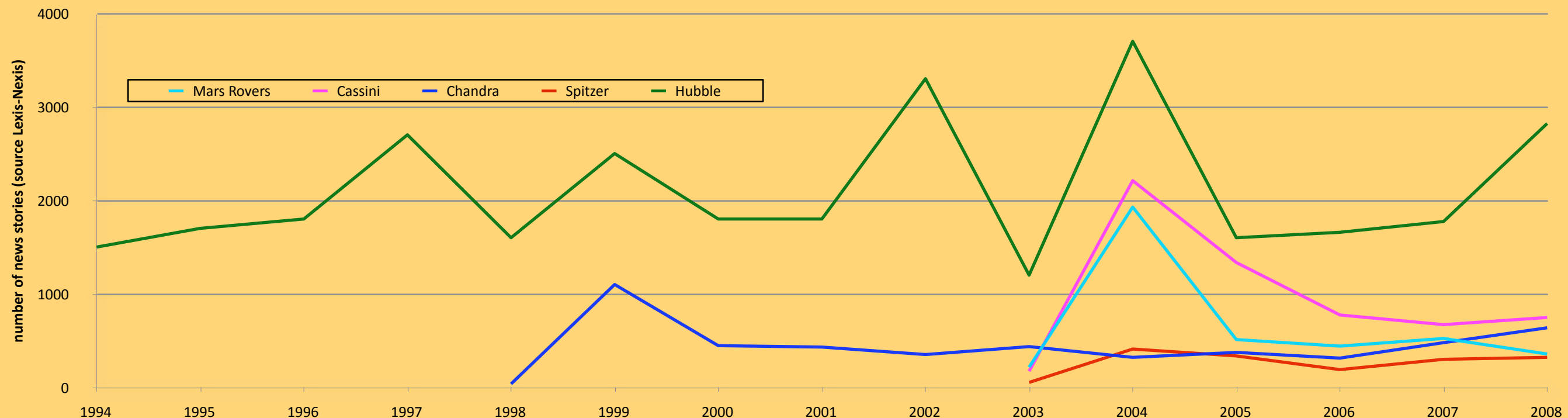
For what the Hubble cameras show us, especially in their new incarnation, is time itself. The distance of the distant objects in these images is measured as much by their relative youth, by how far back in time we must peer to see them, as by their distance measured in a spatial dimension. By now it sounds almost natural to say that among the

It has taught us to see the properties of a universe humans have been able, for most of their history, to probe only with their thoughts.

HST servicing has sustained media impact



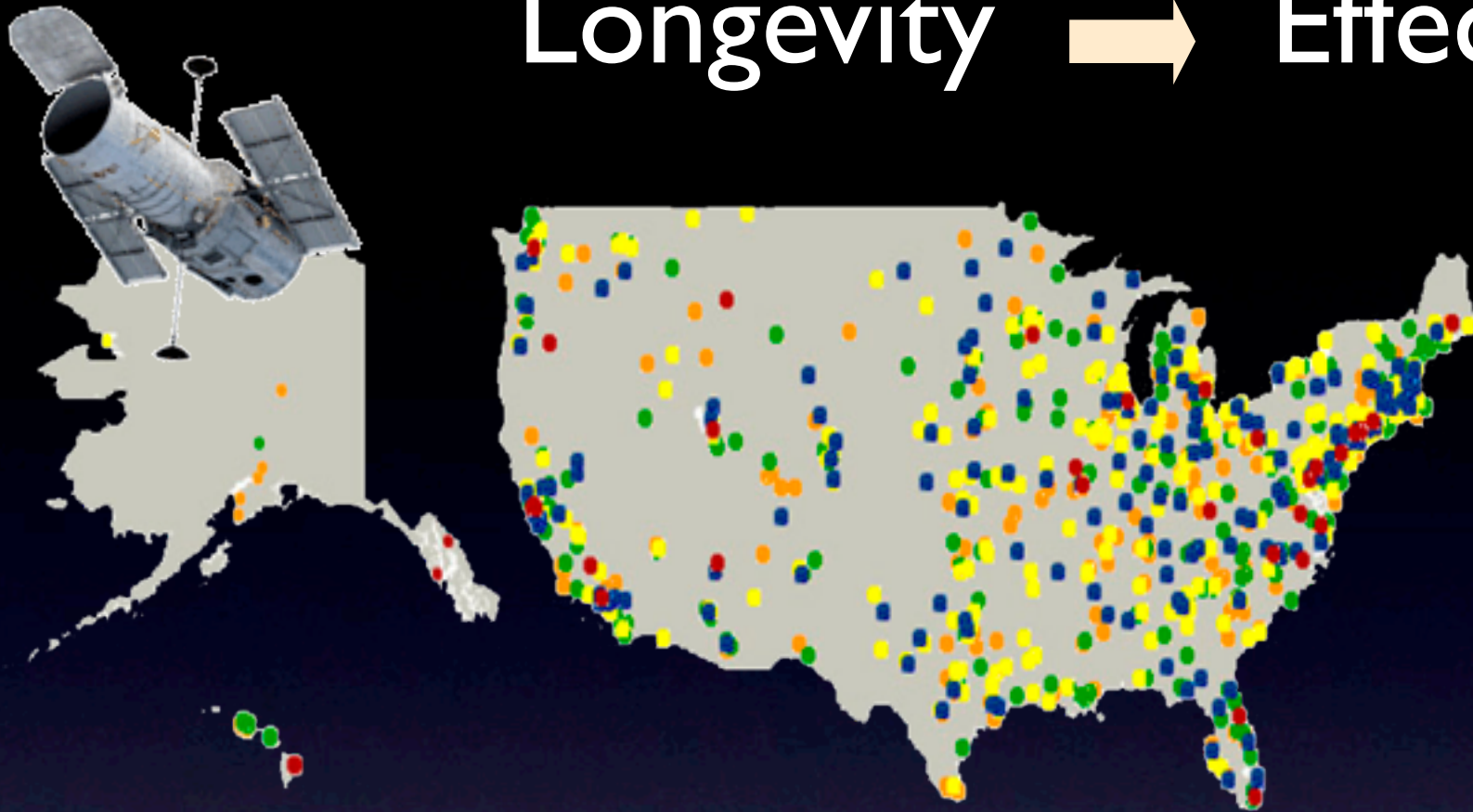
News Coverage of Select Space Observatory & Planetary Missions (1994-2008)



2009-10: news impact of HST



Longevity → Effect Change



Hubble Education Program
now used in all 50 states

Reaches:

506,000 pre- and in-service
teachers

6.3 million students per year



Undergraduate Summer School

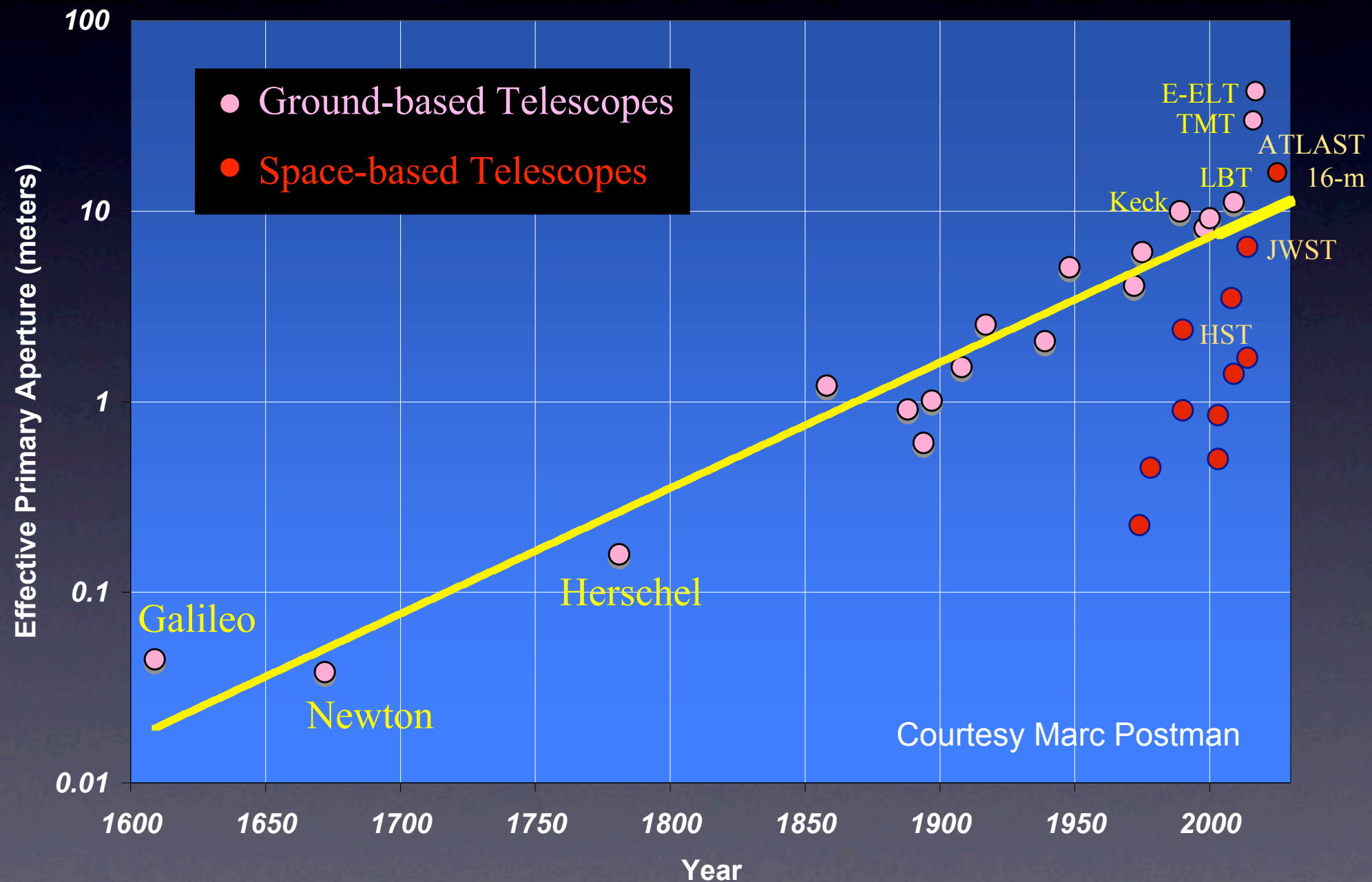
Science and Satellite Servicing

Lesson 4

Longevity can enable the penetration of media and education markets

Missions can become a “brand”

Over four hundred years observational astrophysics has challenged and been enabled by technology



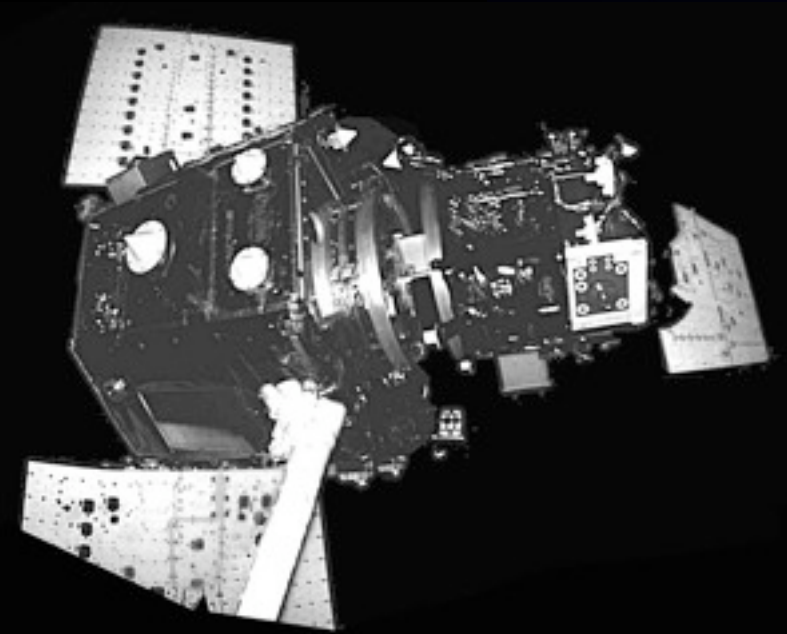
Primary Telescope Aperture vs. Time



Groundbased astrophysics usually build
sustainable facilities and capabilities

The “next big space thing” the James Webb Space Telescope

DARPA Orbital Express

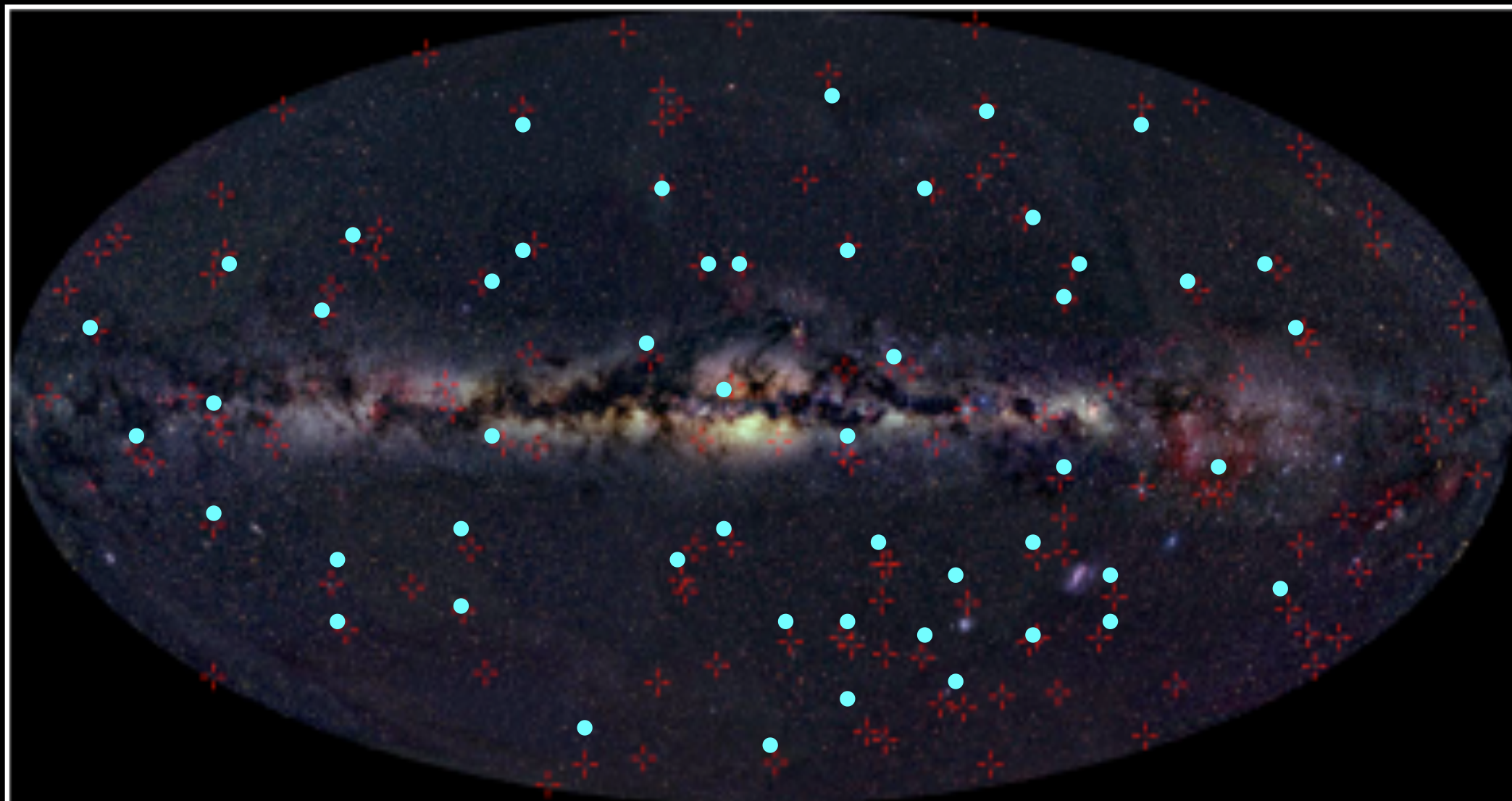


The project aims to demonstrate several satellite servicing operations and technologies including Rendezvous, Proximity Operations and Station Keeping, Capture, Docking, Fluid (Hydrazine) Transfer, and ORU (Orbit Replaceable Unit) Transfer. Source http://en.wikipedia.org/wiki/Orbital_Express



Can we extend the life of of a spacecraft out at L2?

Are we alone?

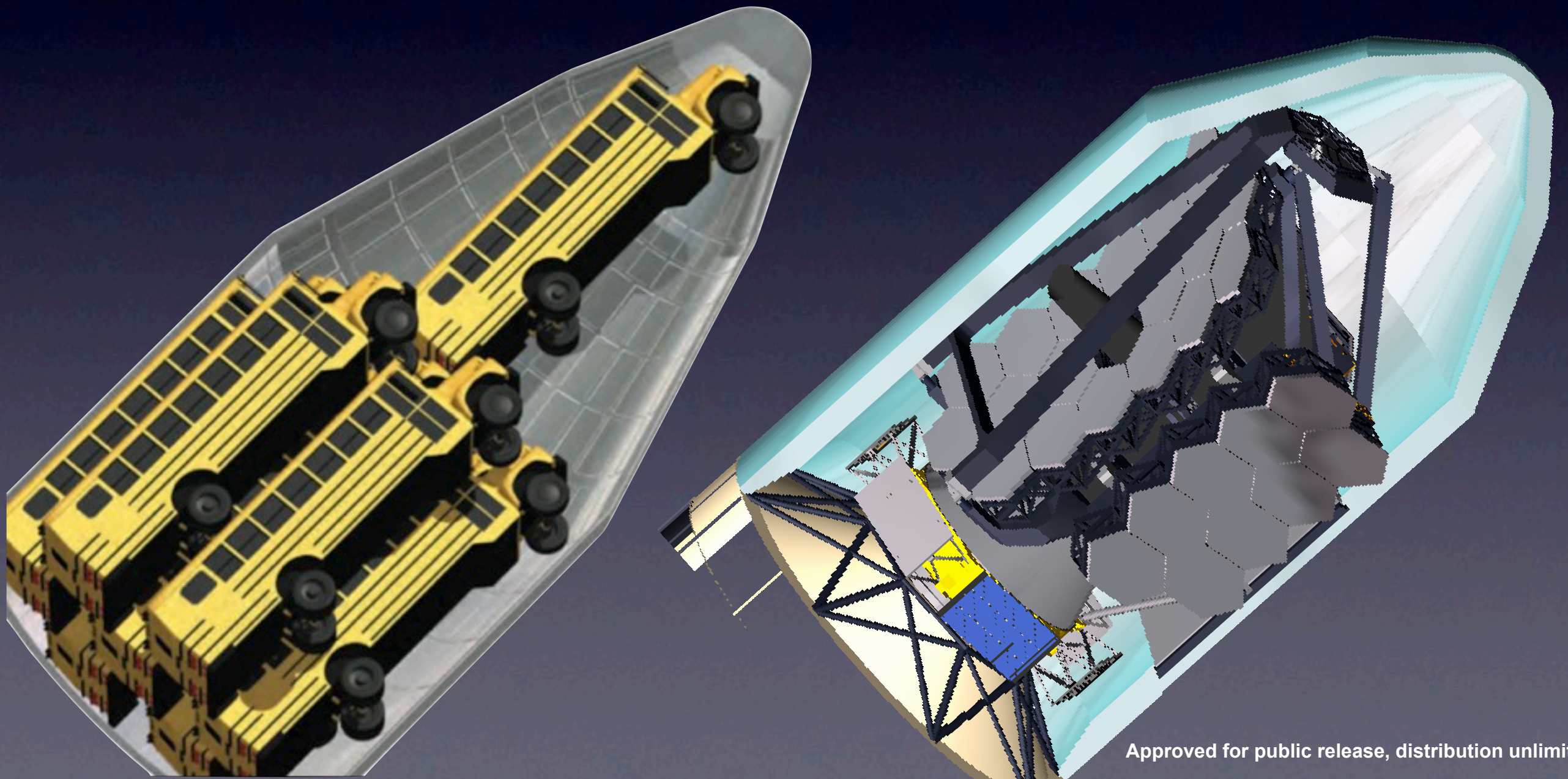


the most favorable nearby stars for habitable planets

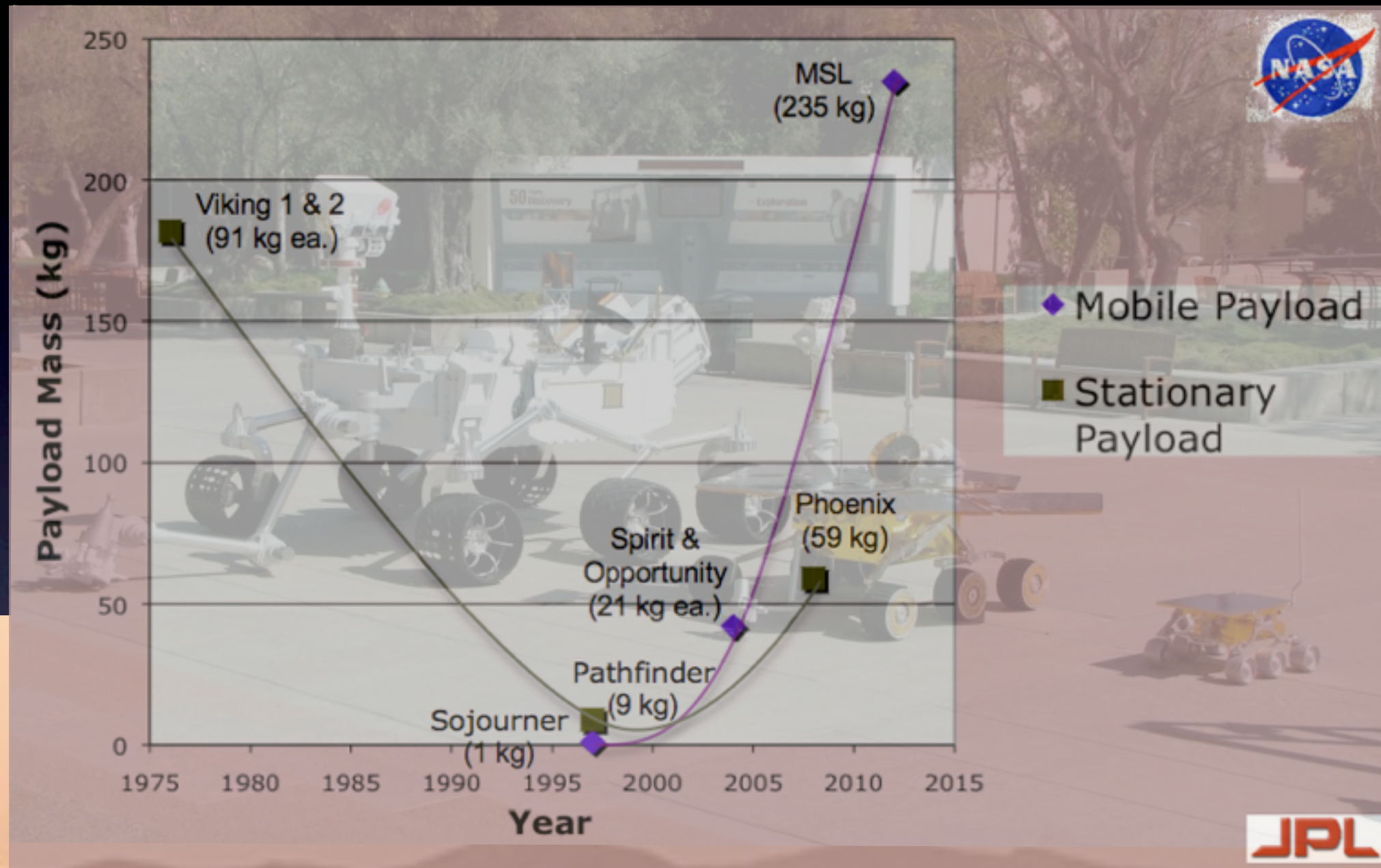


To find and characterize **earth-like planets**
in our solar neighborhood will take
8m ~ 32m class space telescopes

Future NASA heavy-lift will make such telescopes possible



Mars: the changing scale of robotic exploration



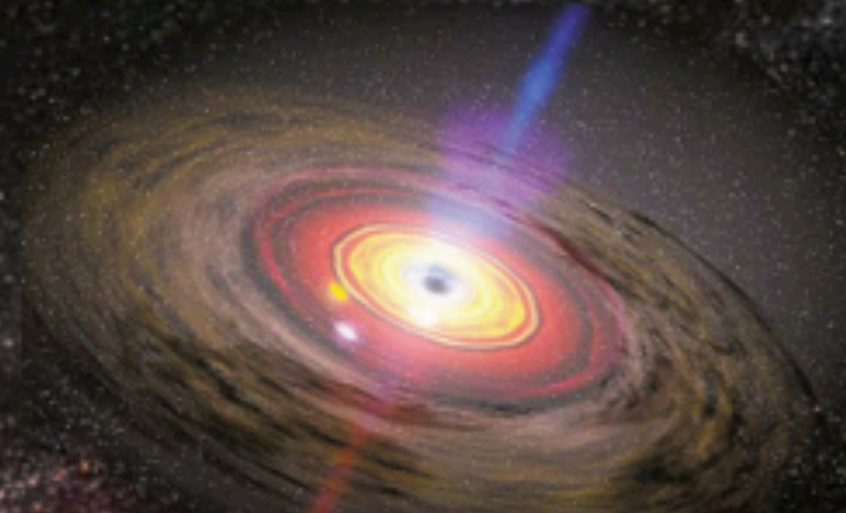
Enabled science - finding the first Black Holes?

The first black holes are the remnants of the first stars in the universe.

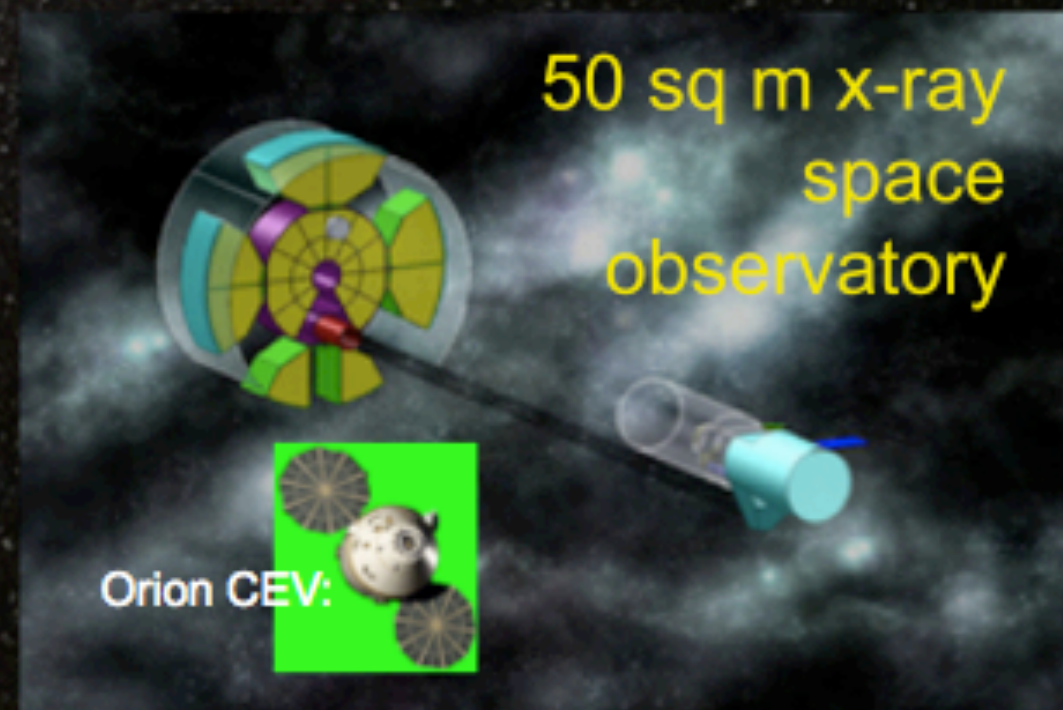


They were created over 13 billion years ago.

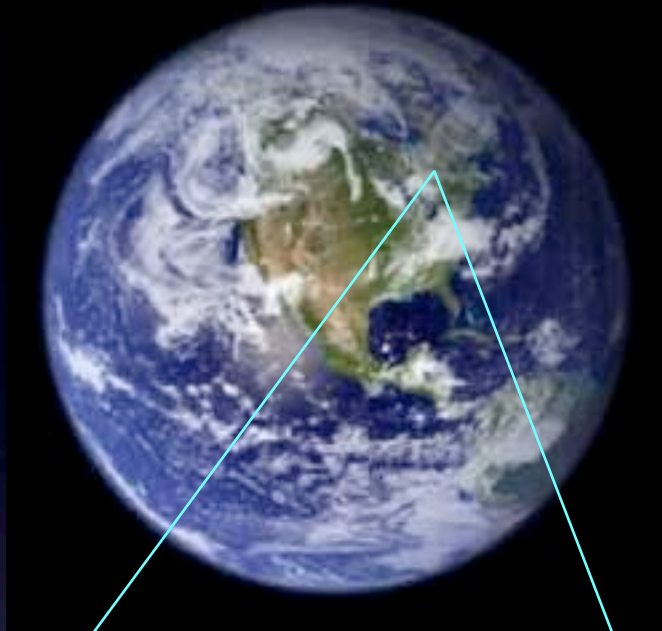
An x-ray observatory with an effective area of 50 square meters could detect them and allow us, for the first time, to trace the cosmic history of stars to their ultimate origin in time.



Ancient black holes are intrinsically very luminous, emitting 10^{41} erg/sec in x-rays, *but* they are so distant that they are 1000x fainter than can be seen by x-ray observatories today.



Science is probably not alone in wanting large, complex, persistent and upgradeable facilities in space



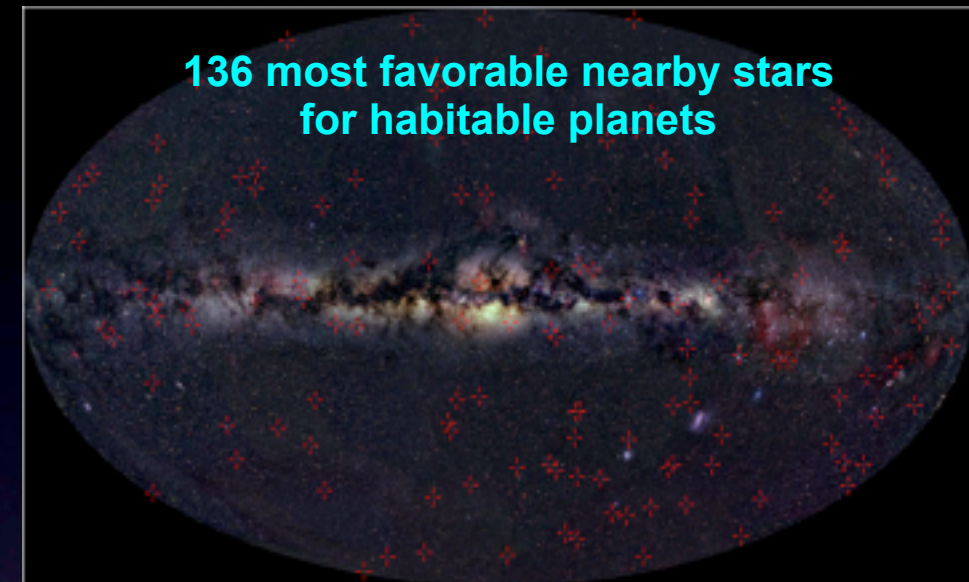
Geostationary orbit



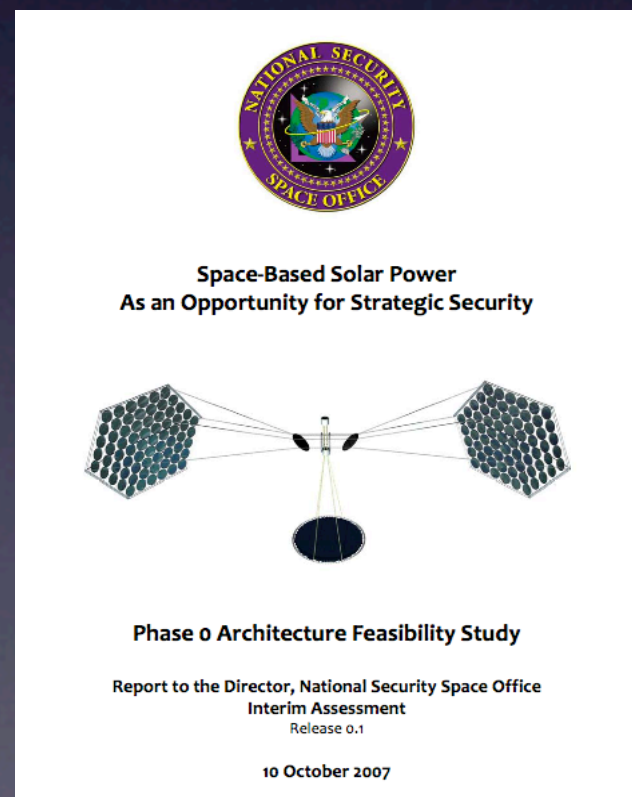
National & Environmental Security



Solar collectors in space



136 most favorable nearby stars for habitable planets




Energy

"I would like to see a reconnaissance of the planetary systems around the nearest 100 stars."

*Carl Sagan, 1994
(paraphrase)*

Are we alone?



Do we understand the threats to our national and global sustainability?

- have we the tools to enable informed and timely decisions?

Can we causally relate the conditions during the Big Bang to the emergence of RNA and DNA?

- how unique was this occurrence; are we alone?

We need ...the right balance between manned space exploration and robotic space exploration. We need to manage the balance between looking up and looking down...

Dr. John Holdren

Extend our reach – move humans beyond low Earth orbit

Explore our Earth, our Galaxy and our Universe

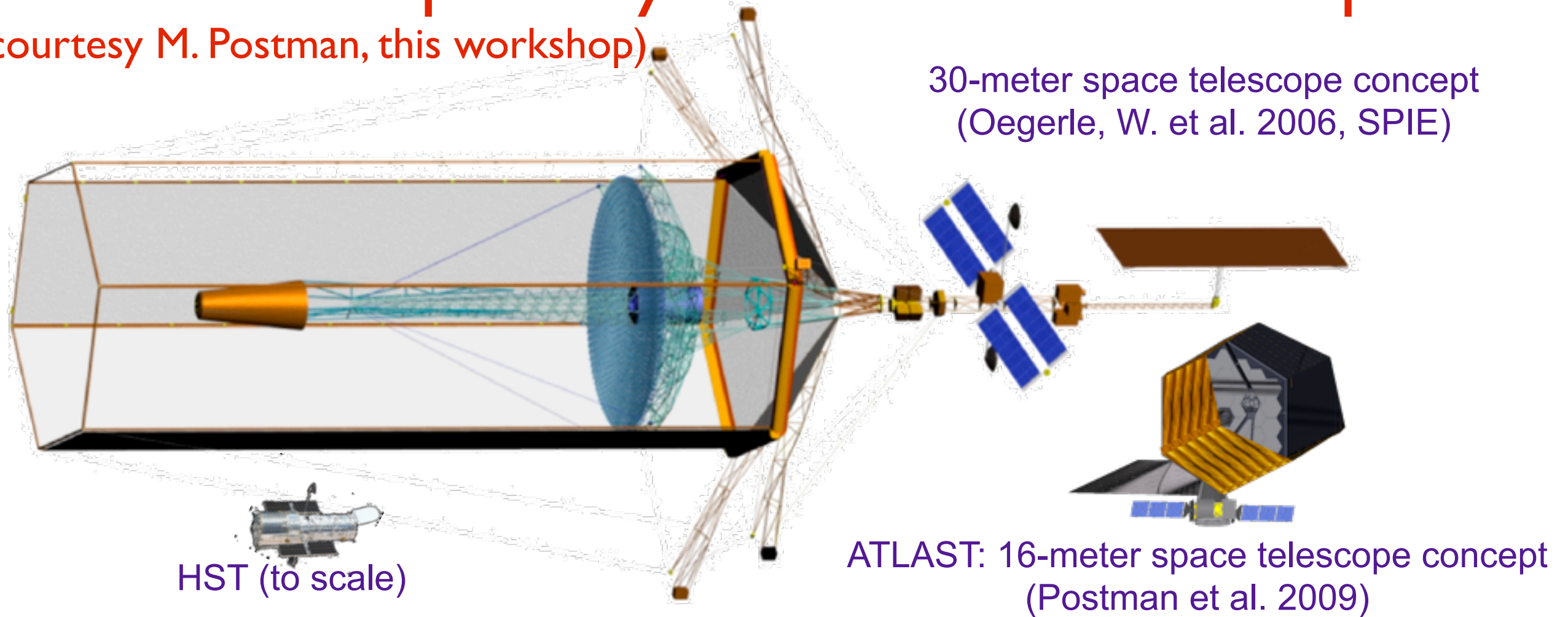
- Assemble and maintain increasingly larger capabilities in space

Expand our knowledge

- Persistent surveillance and reconnaissance for National Security
- Monitor greenhouse gas emissions for arbitration and compliance
- Enable remote sensing of other worlds and search for life
- Explore the structure of the Cosmos and find the first black holes

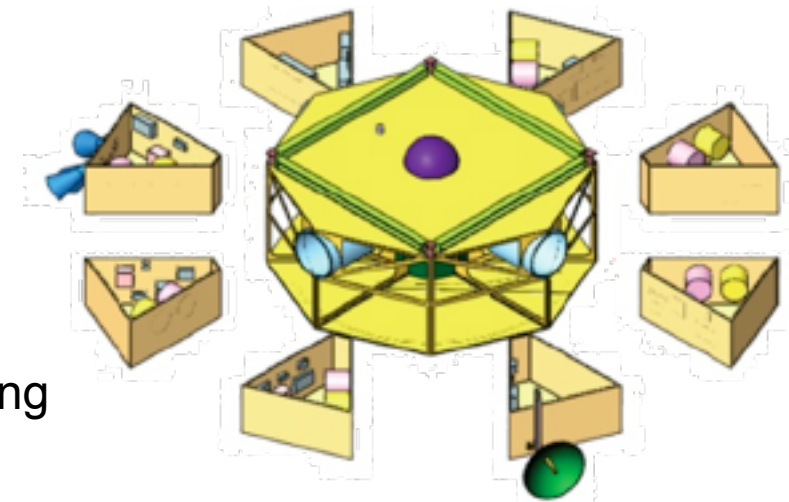
Future telescopes may have to be “born in space.”

(courtesy M. Postman, this workshop)



Key technology areas that need to be matured in order to realize large-aperture **serviceable** telescopes are:

- **Active optical systems** needed for realizing large, lightweight segmented apertures (includes mirror actuators, WFS&C, truss metrology).
- **Standardized modular designs** for spacecraft bus components.
- **Modular, replaceable** instruments, pointing and data-handling systems.
- **Expendables** that can be replenished on-orbit.
- **Computer-aided vision systems** for remote manipulator systems operating with a time delay (cf. Whitcomb’s talk at this workshop).



The future of observational space astrophysics is inexorably linked to NASA's future

If NASA explores a future which requires a sustainable deep space infrastructure - launching, constructing and upgrading observatory-class facilities again becomes feasible

This realizes the full potential of these substantial public investments

This has the demonstrated potential to captivate the public and inspire school children across this Nation; they can take ownership and participate in the adventure of exploration and discovery



Hubble's public impact in 2009

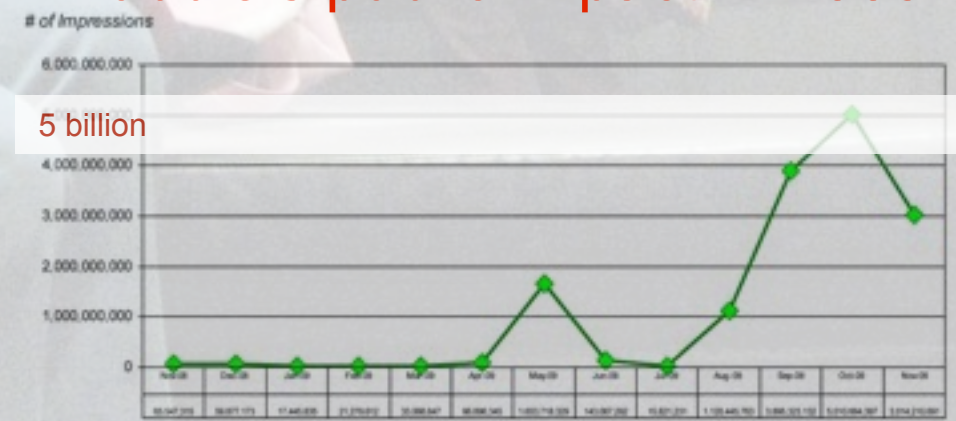
of Impressions



BurrellesLuce

This has the demonstrated potential to captivate the public and inspire school children across this Nation; they can take ownership and participate in the adventure of exploration and discovery

Hubble's public impact in 2009



BurrellesLuce